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PATENT

Attorney Docket No. _____ P43-5007 _____

Assistant Commissioner for Patents
Washington, D.C. 20231

NEW APPLICATION TRANSMITTAL

Transmitted herewith for filing is the patent application of Inventor(s):   Blair A. Barbour

For (title):   **APPARATUS AND METHOD OF INFORMATION EXTRACTION FROM ELECTROMAGNETIC ENERGY BASED UPON MULTI-CHARACTERISTIC SPATIAL GEOMETRY PROCESSING**

Enclosed are:

1.   Papers Required for Filing Date Under 37 CFR 1.53(b):

__40__   Pages of specification

__1__   Pages Abstract

__10__   Pages of claims

__6__   Sheets of drawing

☒   formal (Figs. 1-15)

☐   informal

In addition to the above papers there is also attached: An Information Disclosure Statement (2 pgs.); PTO-Form 1449 (1 pg.); and FOURTEEN (14) references.

CERTIFICATION UNDER 37 CFR 1.10

I hereby certify that this New Application Transmittal and the documents referred to as enclosed therein are being deposited with the United States Postal Service on this date _July 21, 2000_____in an envelope as "Express Mail Post Office to Addressee" Mailing Label Number_ EK-964889116US _____ addressed to the: Assistant Commissioner for Patents, Washington D.C.

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2. **Declaration or oath:**

    ☒   Enclosed (Not Executed)

    ☐   Not Enclosed.

3. **Language:**

    ☒   English

    ☐   Non-English

    ☐   A verified English translation of the

        ☐   specification and claims

        ☐   declaration

    is attached.

4. **Assignment:**

    ☒   An assignment of the invention to   Photon-X, Inc.

        ☐   is attached.

        ☒   will follow

5. **Certified Copy:**

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(Country)	(Appln. No.)	(Filed)
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from which priority is claimed

    ☐   is attached

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6. Fee Calculation:
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CLAIMS AS FILED				
Number Filed		Number Extra	Rate	Basic Fee
				$ 690.00
Total Claims	28	-20 =	8	X $ 18.00	144.00
Independent Claims	6	- 3 =	3	X $ 78.00	234.00
Multiple dependent claim(s), if any		0	+ $260.00	0.00

☐   Amendment canceling extra claims enclosed

☐   Amendment deleting multiple dependencies enclosed

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☒   basic filing fee $1,068.00

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EXPRESS MAIL NO. EK-964889116US

PATENT

APPARATUS AND METHOD OF INFORMATION EXTRACTION FROM ELECTROMAGNETIC ENERGY BASED UPON MULTI-CHARACTERISTIC SPATIAL GEOMETRY PROCESSING

Related Applications

5   This application claims the benefit of U.S. Provisional Application No. 60/145,017, filed July 22, 1999, U.S. Provisional Application No. 60/145,194, filed July 23, 1999, and U.S. Provisional Application No. 60/145,264, filed July 26, 1999.

Field of the Invention

10   The present invention is directed to an apparatus and method that extracts and exploits information conveyed within spatial phase (e.g., three-dimensional geometry) characteristics of electromagnetic energy

15   (e.g., light), and is particularly directed to an apparatus and method that extracts data from multi-characteristic spatial phase processing as a novel approach to providing information useful for imagery and the like.

Background of the Invention

Conventional imaging systems employ intensity-based techniques to handle electromagnetic energy proceeding from a source (e.g., an object). As one

5   example of a conventional system, a spectroscopic system determines spectral (wavelength) composition of objects and scenes. The wavelengths that comprise the collected energy are separated with the use of a dispersive element employing refractive means, such as

10   a prism, or diffractive means, such as a grating. After passing through one of these dispersive elements, the different wavelength components of the wave front propagate in different directions and the intensities of the components are recorded by an array of detector

15   pixels. Such a standard spectrometer is an excellent device for determining the spectral composition of light emanating from a source object, but is unable to maintain two-dimensional spatial integrity of the source object. Typically, such a spectrometer is not

20   capable of determining spectral content on a pixel-by-pixel basis, and merely collects the total intensity of electromagnetic energy proceeding from an object.

Fourier transform and Fabry-Perot interferometer systems are capable of performing imaging spectrometry

and determining the spectral composition of an object
on a pixel-by-pixel basis. However, there are certain
limitations imposed by the geometry of these systems.
For example, in both types of systems, field of view of

5   is severely restricted.

For the Fourier transform interferometer, the
length of the system, combined with the small size of
the mirrors, restricts the field of view because
optical rays will not propagate through the system for

10   large angles. Therefore, the number of pixels that can
be acquired is limited.

For the Fabry-Perot interferometer, a small field
of view is the result of two main effects. First, the
light coming from the source object undergoes multiple

15   reflections within a mirrored optical cavity before
emerging from the system. When the incident light
comes from an off-axis point on the object, it enters
the cavity at an incident angle other than zero.
Consequently, as the light undergoes multiple

20   reflections, it will "walk" along the mirrors and
eventually leak out of the cavity. The result of this
behavior is that, as the field of view increases, the
energy throughput of the system decreases.

The second problem that results in a limitation of the field of view for the Fabry-Perot system has to do with band pass variation with field size. Since the effective mirror separation changes with field angle, so does the filter band pass. To minimize the spectral variation from the center to the edge of the field, the field of view has to be small. However, this will again limit the number of pixels that can be obtained.

Still another problem that can arise with respect to some known systems, such as the Fourier transform interferometer, deals with image registration. Typically, two-dimensional images are acquired as one mirror is scanned. Problems associated with scanning, such as mirror jitter, uneven scanning, or mirror walking, create registration problems between the images in the different spectral bands.

In addition, many known systems employ scanning to acquire the spectral composition of the electromagnetic energy proceeding from a source object. During such scanning, it difficult to obtain the spectral composition in real-time while maintaining a high signal-to-noise ratio. This is not only a problem for the Fourier transform and Fabry-Perot interferometers, but also for electrically scanned systems such as

liquid crystal systems and acousto-optic tunable filter
based imaging spectrometers, which have the additional
problem of relatively low transmission.

Tomographic-based methods are sometimes used for
imaging spectrometry tasks. Tomographic methods negate
the need for scanning. However, the downside of this
technique is that it is computationally intensive,
requiring the mathematically determination of a system
matrix, which is usually application specific.

As mentioned above, conventional imaging
techniques employ intensity collection techniques.
However, it is to be noted that, in distinction,
spatial phase is intensity independent. Spatial phase
characteristics of electromagnetic energy include
characteristics of the plurality of polarizations
(e.g., linear and circular) that are present within the
electromagnetic energy.

As one type of utilization of polarization
characteristics, polarimetry identifies, isolates,
and/or uses a generalized polarization of
electromagnetic energy. In the past, scientists have
used polarimetry to filter imagery for specific
applications. Polarization filters are used to collect
polarization data, and classical polarization theory is

used to determine one level of the spatial phase properties. However, overall spatial phase of a propagated electromagnetic wave can a significant amount of information that is indicative of unique features about the wave history. For example, properties of an electromagnetic wave change as the wave interacts with media and changes as the wave transverses a surface.

In the past, scientists have attempted to build operational imaging polarimeters. None have been successful in providing an operation device that has abilities greater than a two channel orthogonal system. The polarimeters to date have been limited to a single set of four detectors or a rotating polarization analyzer. The rotating analyzer limits the system to static scenes and is not a useful tool for spatial phase analysis.

Another problem that arises for imaging systems that employ moving components, such as a rotating member, deals with the issue of image registration. However, problems associated with rotating, such as optical wedge wobbling, uneven rotating, or beam walking, create registration problems between the images in the different phase channels. With spatial

phase imaging, it is critical that each channel is identical in spatial content as well as angular information. Rotating systems will vary the angular extent of the object and cannot be used effectively.

5   Therefore, while some of the prior art is capable of performing limited polarimetry and other intensity-based applications, it is not capable, for the reasons discussed, of providing true, multi-dimensional, real-time spatial phase imaging.

10   The inventor has recognized that a spatial phase system would solve the above-mentioned problems and also go further into the complete analysis of the phase information, which is contained in the electromagnetic energy. By the scientific analysis of all the

15   radiation being transmitted, reflected, emitted and/or absorbed, one can determine its phase properties. The phase properties are those characteristics that convey information (e.g., an indication of the media through which a wave has passed) that could allow significant

20   imaging abilities. Along these lines, the inventor has recognized that spatial phase is a technology with tremendous benefit potential.

Summary of the Invention

In accordance with one aspect, the present
invention provides an apparatus for information
extraction from electromagnetic energy via
5   multi-characteristic spatial geometry processing.
Means receives electromagnetic energy from a source,
the received electromagnetic energy has a plurality of
spatial phase characteristics. Means separates the
plurality of spatial phase characteristics of the
10   received electromagnetic energy. Means identifies
spatially segregated portions of each spatial phase
characteristic, with each spatially segregated portion
of each spatial phase characteristic corresponding to a
spatially segregated portion of each of the other
15   spatial phase characteristics in a group. Means
quantifies each segregated portion to provide a spatial
phase metric of each segregated portion for providing a
data map of the spatial phase metric of each separated
spatial phase characteristic.

20   In accordance with another aspect, the present
invention provides an imaging apparatus that includes
means for receiving electromagnetic energy proceeding
from an object. Means creates an image of the object

utilizing only spatial phase characteristics of the electromagnetic energy proceeding from the object.

In accordance with another aspect, the present invention provides an imaging apparatus. Means

5 receives electromagnetic energy proceeding from an object, wherein the electromagnetic energy conveying insufficient characterization in the visible and infrared spectrums to permit viable intensity-based and/or frequency-based image creation. Means creates

10 an image of the object utilizing spatial phase characteristics of the electromagnetic energy proceeding from the object.

In accordance with yet another aspect, the present invention provides an imaging apparatus that includes

15 means for receiving electromagnetic energy from an object. The received electromagnetic energy having a plurality of polarization characteristics. Means separates the plurality of polarization characteristics of the received electromagnetic energy. Means creates

20 a plurality of images, each image being created using one of the separated polarization characteristics. Each image has a plurality of pixels, with each pixel of each image corresponding to a pixel of each of the other images in a group. Means quantifies a

polarization metric value at each pixel of each created image. Means determines an imaging value associated with each group of pixels using the quantified values. Means assembles an image using the determined imaging

5   values.

In accordance with still another aspect, the present invention provides a method for information extraction from electromagnetic energy via multi-characteristic spatial geometry processing.

10   Electromagnetic energy is received from a source. The received electromagnetic energy has a plurality of spatial phase characteristics. The plurality of spatial phase characteristics of the received electromagnetic energy are separated. Spatially

15   segregating portions of each spatial phase characteristic are identified, with each spatially segregated portion of each spatial phase characteristic corresponding to a spatially segregated portion of each of the other spatial phase characteristics in a group.

20   Each segregated portion is quantified to provide a spatial phase metric of each segregated portion for providing a data map of the spatial phase metric of each separated spatial phase characteristic.

In accordance with yet still another aspect, the present invention provides a method of creating an image. Electromagnetic energy proceeding from an object is received. An image of the object is created

5 utilizing only spatial phase characteristics of the electromagnetic energy proceeding from the object.

Brief Description of the Drawings

The foregoing and other features and advantages of the present invention will become apparent to those

10 skilled in the art to which the present invention relates upon reading the following description with reference to the accompanying drawings, in which:

Fig. 1 is an example schematic block diagram of an system in accordance with one aspect of the present

15 invention, the system is an imaging system utilizing separated electromagnetic spatial phase characteristics for image creation;

Fig. 2 is an illustration of an example embodiment of an optical system, in accordance with another aspect

20 of the present invention, that may be used to provide the function of separating a plurality of spatial phase characteristics for provision to a plurality of detector arrays of the imaging system of Fig. 1;

Figs. 3A-3D are graphical representations of the spatial phase characteristics that are separated by the optical system of Fig. 2;

Figs. 4A-4D are schematic representations of

5   detector arrays of the system of Fig. 1, and have example representation spatial phase metric values shown for a pixel group;

Fig. 5 is an illustration of an object having a plurality of distinct surfaces;

10   Fig. 6 is an image of the object of Fig. 5 provided via thermal imaging when a temperature gradient between the surfaces does not exist;

Fig. 7 is an image of the object of Fig. 5 provided by the system of Fig. 1 and in accordance with

15   the present invention under the same temperature conditions as the image created for Fig. 6;

Fig. 8 is a representation of an image of an object, with expanded portions that indicate spatial phase differences between the portions;

20   Fig. 9 is a plot indicating contrast during temperature difference change for infrared intensity and polarization phase, as a spatial phase characteristic;

Fig. 10 is a plot indicating contrast over a range of distances from an imaging system for infrared intensity and polarization phase, as a spatial phase characteristic;

5   Fig. 11 is a illustration showing scattering of a bulk of electromagnetic energy proceeding from an object with a minimal amount of the energy reaching the system of Fig. 1;

Fig. 12 is a generalized image-creation embodiment

10   showing another approach to separation of electromagnetic spatial phase characteristics from an object;

Fig. 13 is an example embodiment of an optical system used to separate electromagnetic energy for

15   detector arrays in accordance the approach of Fig. 12;

Fig. 14 is a generalized image-creation embodiment showing another approach to separation of electromagnetic spatial phase characteristics from an object; and

20   Fig. 15 is a plot indicating examples of spatial phase characteristic.

Description of Exemplary Embodiments

An example of one type of information discerning and utilizing system 10 in accordance with the present

invention is schematically shown in Fig. 1. In the
illustrated example, the system 10 is an imaging
system. For example, the system may be a camera
arrangement. However, it is to be understood that the

5   present invention is not limited to an imaging system.
For example, the present invention can be utilized to
provide data transfer, identification, recognition,
etc.

The imaging system 10 provides a real-time image

10 of an object 2 on a display 12, utilizing multi-
characteristic spatial geometric attributes within
electromagnetic energy 4 proceeding from the object.
Specifically, the three-dimensional elliptical shape of
an electromagnetic wave as it sweeps through space

15 provides a multitude of information.

It is to be appreciated that electromagnetic
energy is indented to encompass any and all wave energy
in the spectrum of electromagnetic energy. Examples of
electromagnetic energy include the visible light range,

20 the infrared range, the ultraviolet range, the
microwave range, the x-ray range, the gamma ray range,
and the radio frequency range. For simplicity, the
examples presented herein are discussed primarily with
regard to the portion of the electromagnetic spectrum

that is at or near the visible, infrared and/or

ultraviolet ranges.

Also, the image provided on the display 12 has an

appearance dependent upon the operation of the

5   system 10. For example, the image may provide a

three-dimensional representation of the object 2, a

contrast representation of the object, a surface

orientation/curvature representation of the object, a

material composition representation of the object, or a

10   low light level image (shadow penetration) of the

object. These imaging feature abilities may be

provided by the example embodiments described in more

detail below.

In the illustrated example of Fig. 1, an

15   electromagnetic energy-handling portion 6 receives and

handles the electromagnetic energy 4 proceeding from

the object 2. For the portion of the electromagnetic

spectrum that is at or near the visible, infrared

and/or ultraviolet ranges the electromagnetic energy-

20   handling portion 6 typically includes optical elements.

However, it is to be appreciated that the

electromagnetic energy handling portion 6 will include

components appropriate to receive and handle the

portion of the electromagnetic spectrum that is to be

utilized. For example, the electromagnetic energy-handling portion 6 may include one or more antennas or other receiving structures.

The electromagnetic energy-handling portion 6 specifically includes a plurality of spatial phase separating/isolating/distinguishing components 8A-8X. Each component (e.g., 8A) functions to separate/isolate/distinguish at least one certain, distinct spatial phase attribute or characteristic (e.g., 9A, a polarization characteristic) of the electromagnetic energy 4. The separation/isolation/distinction preferably includes spatial slicing of the electromagnetic wave 4. It is to be appreciated that the components 8A-8X may comprise any suitable structure appropriate to accomplish the separating/isolating/distinguishing function. Examples of structures include filters (e.g., polarization), small diffraction gratings, wires or the like, optical elements employing surfaces at predetermined orientations (e.g., Brewster's angle), and antenna arrays. Preferably, different spatial phase attributes or characteristics are separated/isolated/distinguished via each component (e.g., 8A). In sum, each component (e.g., 8A) provides

a version or representation of an image of the object,
as perceived in the realm of the distinct spatial phase
attribute(s) or characteristic(s) associated with that
component.

5   A plurality of detector arrays 14A-14X is provided
within the imaging system 10 and is associated with the
plurality of separating/isolating/distinguishing
components 8A-8X. Each detector array (e.g., 14A)
detects electromagnetic energy having a certain spatial

10   phase attribute or characteristic. Examples of
detector arrays include CCD and FPA.

Preferably, each detector array (e.g., 14A)
detects the certain spatial phase attribute or
characteristic associated with an associated

15   separating/isolating/distinguishing component
(e.g., 8A). Each detector array (e.g., 14A) has a
plurality of spatially segregated locations
(e.g., pixels) at which a spatial phase metric value is
quantified. It is to be appreciated that although the

20   example embodiment has plural detector arrays, the same
function could be accomplished via division of a lesser
number (e.g., one) of detector arrays into a plurality
of portions (e.g., sub-arrays of pixels). Also, it is

to be appreciated that the division may even be at the singular pixel level.

The spatial phase metric is a value of the spatial phase characteristic at that pixel for the spatial phase characteristic associated with that particular detector array (e.g., 14A) or detector array portion. In the illustrated example, each detector array (e.g., 14A) is an N by M array. Accordingly, the spatial phase metrics provide an N by M map of the characteristic. Further, it is to be appreciated that all of the detector arrays 14A-14X, or detector array portions, are related such that each spatially separated point (e.g., pixel) at each detector array (e.g., 14A), or detector array portion, is related in a group to a corresponding spatially separated point (e.g., pixel) within each of the other detector arrays (e.g., 14B-14X), or detector array portions. Thus, different N by M maps are provided for the different characteristics.

Suitable means 16A-16X are operatively connected 18A-18X for holding/passing the determined spatial phase metric values associated with the plurality of the pixels of the detector array 14A-14X. In the illustrated example, such a function is provided by a

buffer memory (e.g., 16A) that is operatively

(e.g., 18A) connected to a respective detector array

(e.g., 14A).

The plurality of buffer memories 16A-16X is

5   operatively connected 20A-20X to a processor 24. In

the illustrated example of Fig. 1, the processor 24 is

a single processor. However, it is to be appreciated

that compound or parallel processors may be employed.

In general, the processor 24 determines an imaging

10   value for each group of pixels that correspond among

the detector arrays 14A-14X. The imaging value is

utilized to provide a portion of the image that is

provided on the display 12. The imaging values that

are determined by the processor 24 are provided to the

15   display 12 by any suitable means 26. In the

illustrated example of Fig. 1, the means 26 is shown as

a buffer memory 26 that is operatively connected 28

and 30 to the processor 24 and the display 12,

respectively. The buffer memory 26 holds/passes point

20   characterizations of an M by N matrix of the

display 12.

Focusing on the operation of the processor 24, the

processor determines the imaging value for each pixel

by mathematical processes that are performed upon the

spatial phase metric values of each associated group of

pixels. The processing differs dependent upon the

polarization characteristics that are received at each

of the detector arrays 14A-14X. The processing also

5   differs dependent upon the number of detector

arrays 14A-14X that are included within the imaging

system 10. Regardless of these variable aspects, the

processing is based upon the realization that spatial

phase characteristics that are present within

10   electromagnetic energy retain information (e.g., a

history of the origin and propagation of the

electromagnetic wave). The electromagnetic wave has a

unique signature that is exploited by separation for

the plurality of detector arrays 14A-14X, the

15   spatially-separated (e.g., pixel) detection at the

detector arrays, and the processing within the

processor 24. Accordingly, any suitable equation base,

such as a stoke-equation base, may be utilized to

process spatially-separated spatial phase metric

20   values. Thus, spatial phase characteristic metric

values, provided via the detector arrays 18A-18X, are

used to create the image.

Also, it is to be appreciated that the processing

may include first-level processing that generates

spatial phase characteristic metric values using the spatial phase metric values that are provided via the detector arrays 18A-18X. Each particular type of generated spatial phase characteristic metric value may

5   be provided in a complementary size matrix. The generated spatial phase characteristic metric values, with or without the spatial phase characteristic metric values provided via the detector arrays 18A-18X, are then used to create the image. For example, the

10   spatial phase characteristic metric values provided via the detector arrays 18A-18X may include polarization characteristics (e.g., orientation and degree). The generated spatial phase characteristic metric values may represent shape, material, index of refraction,

15   slope, three-dimensionality, polarization computation, phase geometry, object geometry, or molecular composition.

Turning to the separation of electromagnetic energy into different characteristic separation

20   components 8A-8X, and the spatial phase characteristics that are separated, it is to be appreciated that various physical embodiments may be utilized to separate the spatial phase characteristics. The embodiments may differ dependent upon the number of

separations desired and the separations that are

accomplished. It is to be appreciated that the desired

type and number of separations is related to the number

and type of detector arrays 14A-14X, and more

5   importantly the type of processing that occurs within

the processor 24.

It is to be appreciated that the imaging

system 10, with or without the shown electromagnetic

handling portion 6, is considered an imaging apparatus.

10   The distinction only goes to separation state of

received electromagnetic energy. For example, the

shown electromagnetic handling portion 6 would not be

necessary if the electromagnetic energy is provided to

the detector arrays 14-14X is a pre-

15   separated/isolated/distinguished format. However, for

ease of understanding, the disclosed examples include

the separating/isolating/distinguishing feature.

Accordingly, Fig. 2 illustrates an example of one

optical arrangement 100 that provides the function

20   (i.e., provide separated spatial phase characteristics)

of the electromagnetic energy handling portion 6 of the

imaging system 10 of Fig. 1. Specifically, the

separated spatial phase characteristics include

polarization characteristics. However, it is to be

appreciated that the example of Fig. 2 is not a

limitation of the subject invention, but is merely one

embodiment of the electromagnetic energy-handling

portion 6.

5   The optical system 100 is utilized within an

embodiment of the imaging system 10 that has four

detector arrays (i.e., 14A-14D). Also, in the example

of Fig. 2, the source object 2 that is to be imaged is

a physical object 102. Fig. 2 illustrates the

10   object 102 in a schematic (i.e., block) configuration.

It is to be appreciated that the object 102 may take

any form.

       Electromagnetic energy (e.g., light) 104 that

proceeds from the object 102 is received at a first

15   optic arrangement 106, which is preferably is a multi-

element, sequential lens arrangement. The

electromagnetic energy 108 that proceeds from the first

optic arrangement 106 is focused at a field stop 110

and proceeds to a second optic arrangement 112.

20   Preferably, the second optic arrangement 112 is a

multi-element, sequential lens arrangement. The second

optic arrangement 112 collimates the electromagnetic

energy into a beam 114. It should be appreciated that

the cross-section of the electromagnetic beam 114 is

representative of electromagnetic energy from the

entire object 102.

A pyramid prism 116 is located such that the

beam 114 impinges upon each of four prism faces (only

5   two faces 120A and 120B shown for simplicity).

Specifically, the prism 116 is at a pupil plane that is

oriented perpendicular to the beam. Associated with

each of the prism faces (e.g., 120A and 120B) is a

reflecting surface (only two shown, e.g., 124A

10   and 124B). Reflected beams (only two shown, e.g., 126A

and 126B) that proceed from the reflecting surfaces

(e.g., 124A and 124B) impinge on respective

phase/polarization filters (only two of the four

filters shown for simplicity, e.g., 130A and 130B).

15   Accordingly, in the example of Fig. 2, the pupil plane

is split or separated into a plurality (i.e., four)

parts.

Each phase/polarization filter (e.g., 130A)

permits passage of only a certain polarization

20   characteristic of the electromagnetic energy. For

example, the first phase/polarization filter 130A

passes only linear polarization at a zero degree phase.

Such a polarization characteristic is illustrated by

the graphic of 3A. The second phase/polarization

filter 130B passes only linear polarization at a 45°

phase. Such a polarization characteristic is

illustrated by the graphic of Fig. 3B. The third

phase/polarization filter passes only linear

5   polarization at a 90° phase. Such a polarization

characteristic is illustrated by the graphic of

Fig. 3C. The fourth phase/polarization filter passes

only circular (e.g., left-hand/right-hand)

polarization. Such a polarization characteristic is

10   illustrated by the graphic of Fig. 3D. Accordingly,

in the example of Fig. 2, the four parts from the pupil

plane are each filtered in a different manner to create

four different characteristic conveying beams

(e.g., 134A and 134B), wherein each beam has a

15   different "slice" of the overall spatial properties of

the electromagnetic energy 104.

Turning again to Fig. 2, a third optic

arrangement 132 is provided for focusing

electromagnetic energy (e.g., 134A and 134B) as a

20   plurality of images for the plurality of detector

arrays 14A-14D. Specifically, the third optic

arrangement 132 focuses the electromagnetic energy

proceeding from the first reflecting surface 124A that

passes through the first phase/polarization filter 130A

onto the first detector array 14A. Similarly, the third optic arrangement 132 focuses the electromagnetic energy that proceeds from the second reflecting surface 124B that passes through the second

5   phase/polarization filter 130B onto the second detector array 14B. Similar focusing occurs for the third and fourth detector arrays. Preferably, the third optic arrangement 132 is a multi-element, sequential lens arrangement. One important feature that is associated

10   with the embodiment of Fig. 2 is that the optical elements are non-moving.

It should appreciated that the focusing of the images onto the detector arrays 14A-14D is such that there is a point-by-point (e.g., pixel-by-pixel)

15   correspondence between all of the detector arrays. In other words, each certain pixel position at each detector array (e.g., 14A) corresponds to an identical certain pixel position at all of the other detector arrays (e.g., 14B-14D). Thus, the dissected

20   polarization characteristics for each pixel can be processed within the processor 24 (Fig. 1).

Such a correspondence of the dissected polarization characteristics is shown by the representations of Figs. 4A-4D. Specifically, a

pixel 140A location on the first detector array 14A has a certain polarization metric value that is represented by certain shading within Fig. 4A. It is to be appreciated that the polarization metric value for the polarization characteristic (e.g., linear polarization at zero phase) has a value that is dependent upon the image as provided to the first detector array 14A for the certain polarization characteristic. The Figs. 4B-4D have similar graphical shading representations for pixels 140B-140D, respectively, to indicate polarization metric values of their associated polarization characteristics (e.g., linear polarization at 45° in Fig 4B, linear polarization at 90° in Fig. 4C, and circular polarization in Fig. 4D).

Again, turning to the imaging system 10 of Fig. 1, the processor 24 utilized the mapping created by the separation. Specifically, the processor 24 performs the mathematical process on the polarization metric values within the group for each pixel location to provide an image value that will be displayed to create the image at the display 12 for the certain pixel location.

Turning to the benefits associated with an imaging apparatus in accordance with the present invention, an

image created utilizing polarization characteristics is

not subject to the limitations associated with various

known imaging techniques. To illustrate, attention is

directed to Fig. 5, which shows a three-dimensional

5   object 150. For simplicity, the object 150 is shown as

a cube. In Fig. 5, the cube 150 is oriented such that

three surfaces 152, 154, and 156 are presented.

Edges 160-164 separate the three presented

surfaces 152-156.

10   Now, assume that the cube 150 is at an ambient

temperature and does not have any temperature gradient

between any portion (e.g., the surfaces 152-156).

Conventional infrared imaging of the cube 150 produces

an image 168 as shown in Fig. 6. Specifically, so long

15   as the cube 150 is at a thermal gradient to its

background, the cube is distinguishable, but because of

the lack of a thermal gradient between the portions of

the cube, only an outline of the cube is discerned.

When the cube 150 of Fig. 5 is imaged with the

20   imaging apparatus in accordance with the present

invention, an image 170 (Fig. 7) would be provided on

the display 12. Specifically, the image 170 clearly

shows three distinct surface representations 172-176

separated by three distinct edge representations

180-184. Again, the ability of the imaging system 10
to provide the image 170 is based upon the fact that
the polarization of the electromagnetic energy
proceeding from each of the three surfaces 152-156 of

5   the cube 150 of Fig. 5 has some difference in
polarization characteristics.

It is not so important as to what the differences
in the polarization characteristics are, but it is that
a difference exists which permits the image 170 to be

10   created. This concept is illustrated by the
representation of an image of a two dimensional object
shown by Fig. 8. The image of the object (represented
merely by the text "image") is comprised of pixels that
each are associated with a different spatial phase

15   identification. In the example of Fig. 8, three pixels
are selected to stand out, and a graphical
representation indicating spatial phase identification
is provided for each pixel. It is to be noted that the
different pixels have different spatial phase

20   identifications.

The ability to create an image that has
discernable detail is related to the amount of
polarization contrast, whatever the contrast may be,
that can be discerned to create the image. Fig. 9

illustrates contrast that may be discerned for image

creation in both an infrared intensity that is known in

the prior art, and a polarization phase analysis in

accordance with the present invention. Specifically,

5   at a very large temperature difference, either cold or

hot, from a reference point, infrared intensity will

provide suitable contrast to permit an image to be

created using an infrared technique. However, when a

temperature difference does not exist, an image with

10   viable resolution cannot be created using infrared

intensity. In contrast, polarization-phase imagery

remains at a relatively high contrast regardless of

temperature gradient.

Other benefits to polarization phase imagery

15   exist. For example, for an intensity-based imaging

system to provide a usable image, sufficient intensity

must be supplied to the imaging system. However,

intensity decreases as a square of the inverse of the

distance between an object and an imaging system.

20   Thus, as shown in Fig. 10, at a relatively close range,

an infrared intensity imaging system would provide for

relatively high contrast. However, at increased

distances, the intensity would decrease to the point

that contrast is insufficient for imaging purposes. In

distinction, a polarization phase-based image can be

generated because polarization characteristics do not

decrease, or decrease little in relationship to

distance. Thus, so long as some electromagnetic energy

5   is received at the imaging system 10 of Fig. 1, a

polarization-based image can be created.

It should be further realized that, in view of the

fact that only a certain minimal amount of

electromagnetic energy is necessary for the creation of

10   a polarization phase-based image, a relatively large

amount of electromagnetic energy that proceeds from an

object may be lost or unused without effecting the

ability of the system to provide an image. For

example, as shown in Fig. 11, an object 190 emits

15   electromagnetic energy 192. A dense scattering media

194 is located between the object and the imaging

system 10 and its associated optical system 100. The

dense scattering media 194 causes a scattering (e.g.,

random dispersion) 196 of the electromagnetic energy.

20   Some electromagnetic energy 198 proceeds from the

dense scattering media 194 to the optical system 100

and thus to the imaging system 10. This

electromagnetic energy 198 will provide sufficient

information within its polarization characterization to permit an image to be provided of the object 190.

It is to be appreciated that the dense scattering media 194 may alter polarization characteristics. This is due to the fact that polarization characteristics retain a complete history. However, it is to be appreciated that sufficient information contained in the polarization characteristics to permit the image of the object 190 to be created.

Fig. 12 illustrates another approach to separation of electromagnetic spatial phase characteristics from an object 260. Electromagnetic energy 262 proceeding from the object 260 is provided to a plurality of isolation components 264-272. The isolation components 264-272 operate to provide certain spatial phase characteristics 274-282 (e.g., slices of the spatial phase of the electromagnetic energy 262). The characteristics 274 are near pure such that the portions 284-292 of the image associated with the respective characteristic are completely separate. Thus, each map created is for a purely distinct spatial phase characteristic.

This complete separation or isolation is accomplished by each isolation component (e.g., 264)

operating effectively at 100% efficiency to strip out

all spatial phase characteristics except for the

desired spatial phase characteristic. As with the

other embodiments, the separated characteristics are

5   processed and used (represented schematically by the

traces 294) to create an image 296.

Fig. 13 illustrates an example embodiment of an

optical system 200 that is utilized to provide

separated spatial phase (e.g., polarization)

10   characteristics in accordance with the approach shown

in Fig. 12. Of course, it is to be appreciated that

although the example of Fig. 13 is an optical system,

the approach of Fig. 12 is not so limited. Similar to

the embodiment shown in Fig. 2, the elements of the

15   embodiment of Fig. 13 do not move (e.g., non-scanning).

The optical system 200 is utilized within an

embodiment of an imaging system (e.g., similar to the

imaging system 10 of Fig. 1) that has four detector

arrays (i.e., 14A-14D). In the example of Fig. 13, the

20   source object that is to be imaged is a physical

object 202.

Electromagnetic energy (e.g., light) 204 that

proceeds from the object 202 is received at a first

optic arrangement 206, which is preferably is a multi-

element, sequential lens arrangement. The
electromagnetic energy 208 that proceeds from the first
optic arrangement 206 is focused at a field stop 210
and proceeds to a second optic arrangement 212.

5   Preferably, the second optic arrangement 212 is a
multi-element, sequential lens arrangement. The second
optic arrangement 212 collimates the electromagnetic
energy into a beam 214. It should be appreciated that
the cross-section of the electromagnetic beam 214 is

10   representative of electromagnetic energy from the
entire object 202.

A first interference filter 216 is located in the
path of the beam 214. The first interference
filter 216 reflects certain polarization

15   characteristic(s) and passes certain polarization
characteristic(s) of the electromagnetic energy. The
reflected electromagnetic energy provides a beam 218,
and the passed electromagnetic energy impinges upon a
first reflecting surface 222. A beam 224 extends from

20   the first reflecting surface 222. The first
interference filter 216 and the first reflecting
surface 222 are at different orientations (e.g.,
different angles). Thus, the beam 218 and the beam 224
proceed along different paths.

A second reflecting surface 230 and a second
interference filter 232 receive the beams 218 and 224.
Again, because of the properties of the second
interference filter, the electromagnetic energy is

5   further separated based upon polarization properties.
Also, because of a difference in orientation of the
second reflecting surface 230 and the second
interference filter 232 the separated electromagnetic
energy is directed along different paths. The result

10   of the separations is four beams (only two shown,
e.g., 236A and 236B), with polarization characteristic
distinction for each beam.

A third optic arrangement 240 is provided for
focusing the electromagnetic energy (e.g., 242A

15   and 242B) as a plurality of images for the plurality of
detector arrays 14A-14D. Preferably, the third optic
arrangement 132 is a multi-element, sequential lens
arrangement. It should appreciated that the focusing
of the images onto the detector arrays 14A-14D is such

20   that there is a point-by-point (e.g., pixel-by-pixel)
correspondence between all of the detector arrays. In
other words, each certain pixel position at each
detector array (e.g., 14A) corresponds to an identical
certain pixel position at all of the other detector

arrays (e.g., 14B-14D). Thus, the dissected

polarization characteristics for each pixel can be

processed within the processor 24 (Fig. 1).

Fig. 14 illustrates another approach to separation

5   of electromagnetic spatial phase characteristics from

an object 302. Electromagnetic energy proceeding from

the object 302 is focus by a lens arrangement 304 onto

a detector array 306. The detector array 306 has a

plurality of discrete locations (e.g., pixels). Each

10   location or pixel collects and stores spatial phase

characteristics (e.g., slices of the spatial phase of

the electromagnetic energy). The spatial phase

identification of the electromagnetic energy at each

location is the stores in a matrix 310 (the

15   identification of the electromagnetic energy at each

location is represented by a graphical symbol). Thus,

the matrix 310 is the map. Further processing can then

be accomplished via various used of location-by-

location (e.g., pixel-by-pixel) analysis. For example,

20   gradients between adjacent locations (pixels) are

analyzed, a series of locations (pixels) are analyzed

for curvature. Also, each row or column can be

considered to be a slice of the electromagnetic energy.

Accordingly, slicing of the electromagnetic energy to

derive information can be accomplished in different ways.

Fig. 15 is a graphical example that illustrates spatial phase characteristics that may be associated with a single location (e.g., pixel) in the example of Fig. 14 (or in some of the other above-described examples). In the example, the characteristics are separated by identifiers that are also referred to as bins. Further, the bins include polarization characteristics (e.g., the first four bins), angle, and material.

Some possibilities for the present invention include reconstruction of surface geometry (3-D) via constant phase contrast (which is typically constant for polarization), penetration of shadows via amplitude-independent (intensity-independent) processing, detection through scattering media. It is contemplated that spatial phase could be used in conjunction with any system to add discrimination ability. For example, spatial phase technology accordingly to the present invention can be effectively added to any sensor to expand that sensor capability to include phase information. Further, imaging data derived via the spatial phase technology accordingly to

the present invention can be merged or fused with imaging data derived via other methods (e.g., regular imaging, infrared imaging) to provide an enhanced image.

Specific applications for the subject invention are numerous. Some applications are is the medical field (non-invasive glucose, ocular analysis for disease, etc., cancer (e.g., skin, breast, cervical, prostrate) diagnosis, and identification of DNA taggents and blood analytes. Other applications are to be found in industry, such as non-destructive inspections, 3-D profiling, telecommunications, remote sensing, and process control. For example, crystal growth can be monitored in real-time to immediately provide information regarding imperfections. Licensed government use could include weapons testing, and enemy detection and observation.

Still further, the three dimensional imaging ability that the present invention provides lends itself to a myriad of possibilities such as real-time contour display of a map or the like. The spatial phase ability of the present invention is also useful for feature extraction and classification. Such specific application could entail pattern recognition,

image enhancement, and scene analysis. For example, movement of objects, people, or the like can be monitored via the use of a spatial-phase identification marker or tag.

5   As a specific example, the present invention is usable to identify specific items that are marked with predefined tags. Each tag provides for at least one certain spatial phase characteristic within the electromagnetic energy proceeding from the tag. The

10   certain spatial phase characteristic is identifiable, and thus the tag provided on the item is identifiable. The item may be any item, such as a person, and the tag may have any suitable construction.

Still further, because the electromagnetic energy

15   may be at any portion of the spectrum, the applications may utilize any medium of electromagnetic conveyance to an apparatus in accordance with the present invention. For example, air/space (e.g., wireless), wire, fiber optic cable, storage media, and the like are all

20   suitable conveyance mediums.

From the above description of the invention, those skilled in the art will perceive improvements, changes and modifications. Such improvements, changes and

modifications within the skill of the art are intended
to be covered by the appended claims.

Having described the invention, the following is claimed:

1.   An apparatus for information extraction from electromagnetic energy via multi-characteristic spatial geometry processing, said apparatus comprising:

means for receiving electromagnetic energy from a source, the received electromagnetic energy having a plurality of spatial phase characteristics;

means for separating the plurality of spatial phase characteristics of the received electromagnetic energy;

means for identifying spatially segregated portions of each spatial phase characteristic, with each spatially segregated portion of each spatial phase characteristic corresponding to a spatially segregated portion of each of the other spatial phase characteristics in a group; and

means for quantifying each segregated portion to provide a spatial phase metric of each segregated portion for providing a data map of the spatial phase metric of each separated spatial phase characteristic.

2. An apparatus as set forth in claim 1, wherein said apparatus is an imaging apparatus for providing an image of an object as the source, and includes means for determining an imaging value associated with each group of corresponding segregated portions using the spatial phase metrics, and means for assembling an image of the object using the determined imaging values.

3. An apparatus as set forth in claim 1, wherein the spatial phase characteristics of the electromagnetic energy include polarization characteristics of the electromagnetic energy.

4. An apparatus as set forth in claim 1, wherein said means for providing a data map includes providing the map to indicate spatial phase change.

5. An apparatus as set forth in claim 1, wherein said means for quantifying each segregated portion to provide a spatial phase metric includes associating an information value with each segregated portion.

6.   An apparatus as set forth in claim 1, wherein the electromagnetic energy conveying insufficient characterization in the visible and infrared spectrums to permit viable intensity-based and/or frequency-based usage.

7.   An apparatus as set forth in claim 1, wherein said apparatus is a single view imaging apparatus for providing an image of an object as the source, and includes means for determining an imaging value associated with each group of corresponding segregated portions using the spatial phase metrics, and means for assembling a three dimensional image representation of the object using the determined imaging values.

8.   An apparatus as set forth in claim 7, wherein said means for assembling a three dimensional image representation includes means for using determined values representative of slope functions of the object.

9.   An apparatus as set forth in claim 7, wherein said means for assembling a three dimensional image representation includes means for using determined values representative of surface shapes of the object.

10. An apparatus as set forth in claim 7, wherein said means for assembling a three dimensional image representation includes means for using determined values representative of surface contour of the object.

11. An apparatus as set forth in claim 1, wherein said apparatus is an imaging apparatus for providing an image of an object as the source, and includes means for determining an imaging value associated with each group of corresponding segregated portions using the spatial phase metrics and indicative of material composition of the object associated with each group of corresponding segregated portions, and means for assembling an image representation of the object indicative of material composition using the determined imaging values.

12. An apparatus as set forth in claim 1, wherein said apparatus is an imaging apparatus for providing an image of an object obscured by an electromagnetic energy scattering media that permits a minimal amount of electromagnetic energy passage and includes means for determining imaging values from the minimal amount of electromagnetic energy.

13.   An apparatus as set forth in claim 1, wherein said apparatus is a communication apparatus and said means for quantifying each segregated portion to provide a spatial phase metric includes determining a information value from each segregated portion.

14.   An imaging apparatus comprising:

means for receiving electromagnetic energy proceeding from an object; and

means for creating an image of the object utilizing only spatial phase characteristics of the electromagnetic energy proceeding from the object.

15.   An apparatus as set forth in claim 14, wherein said means for receiving and said means for creating include components that do not move relative to each other.

16.   An apparatus as set forth in claim 13, wherein the spatial phase characteristics of the electromagnetic energy include polarization characteristics of the electromagnetic energy.

17. An imaging apparatus comprising:

means for receiving electromagnetic energy proceeding from an object, the electromagnetic energy conveying insufficient characterization in the visible and infrared spectrums to permit viable intensity-based and/or frequency-based image creation; and

means for creating an image of the object utilizing spatial phase characteristics of the electromagnetic energy proceeding from the object.

18. An imaging apparatus comprising:

means for receiving electromagnetic energy from an object, the received electromagnetic energy having a plurality of polarization characteristics;

means for separating the plurality of polarization characteristics of the received electromagnetic energy;

means for creating a plurality of images, each image being created using one of the separated polarization characteristics, each image having a plurality of pixels, with each pixel of each image corresponding to a pixel of each of the other images in a group;

means for quantifying a polarization metric value at each pixel of each created image;

means for determining an imaging value associated with each group of pixels using the quantified values; and

means for assembling an image using the determined imaging values.

19. A method for information extraction from electromagnetic energy via multi-characteristic spatial geometry processing, said apparatus comprising:

receiving electromagnetic energy from a source, the received electromagnetic energy having a plurality of spatial phase characteristics;

separating the plurality of spatial phase characteristics of the received electromagnetic energy;

identifying spatially segregating portions of each spatial phase characteristic, with each spatially segregated portion of each spatial phase characteristic corresponding to a spatially segregated portion of each of the other spatial phase characteristics in a group; and

quantifying each segregated portion to provide a spatial phase metric of each segregated

portion for providing a data map of the spatial phase
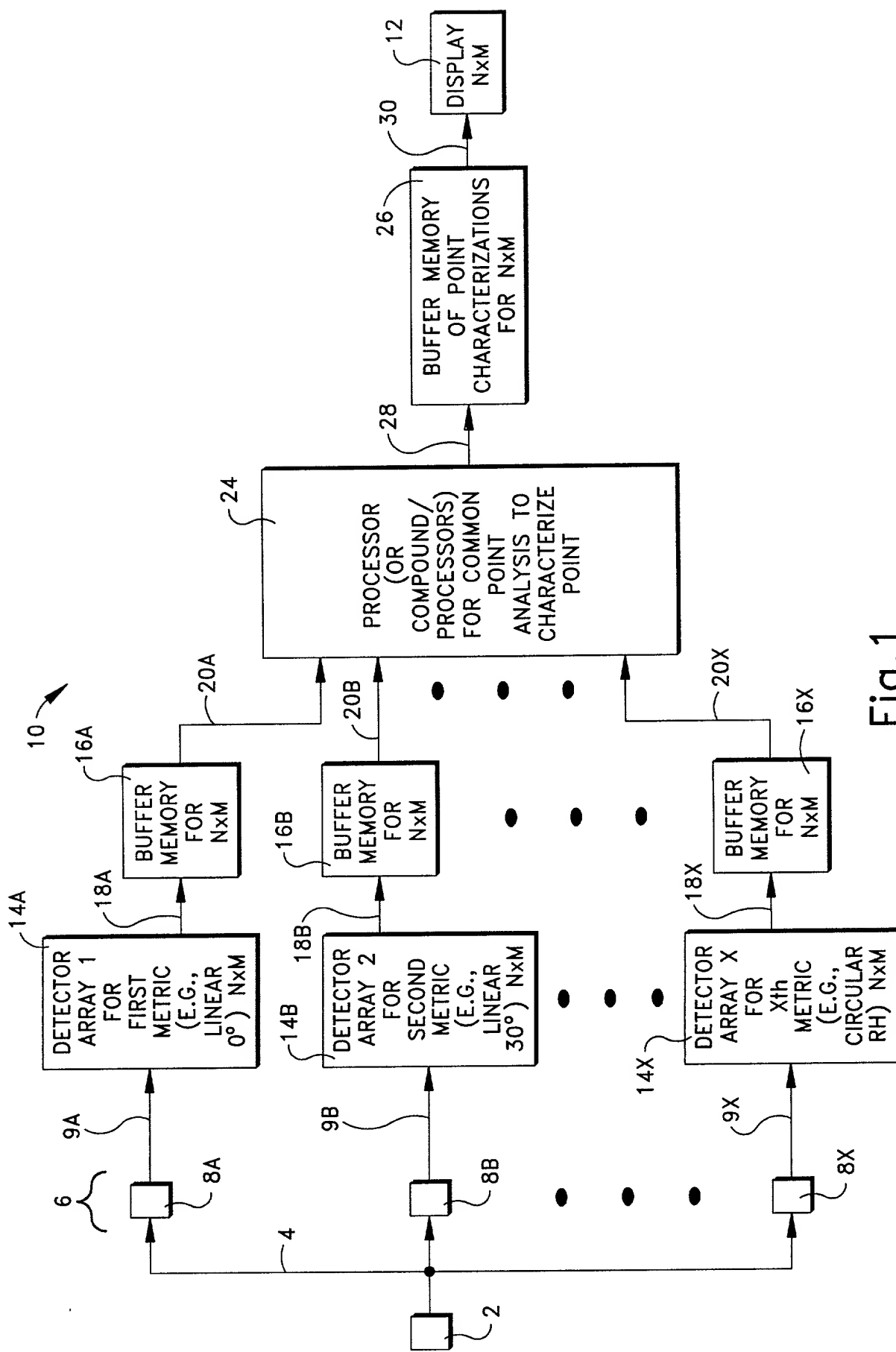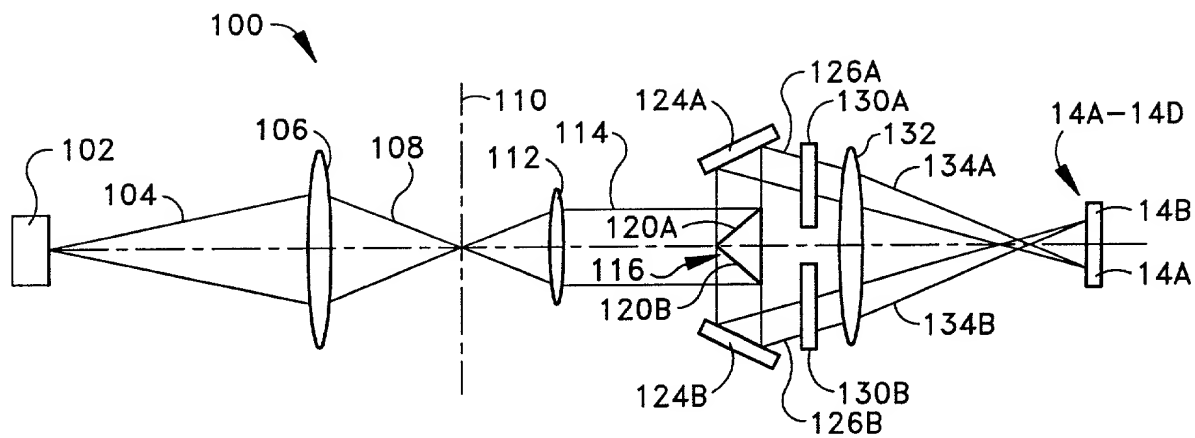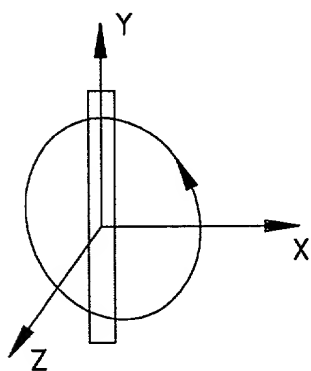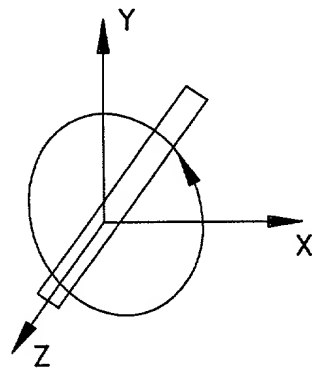metric of each separated spatial phase characteristic.

20. A method as set forth in claim 19, including
processing the spatial phase metrics to derive
information.

21. A method as set forth in claim 19, wherein
said step of separating includes discerning a three-
dimensional shape aspect of the ellipsoidal shape of
the electromagnetic energy.

22. A method as set forth in claim 19, wherein an
image of an object is provided, an imaging value is
determined for each group of corresponding segregated
portions using the spatial phase metrics, and the image
is assembled using the determined imaging values.

23. A method as set forth in claim 19, wherein
the spatial phase characteristics of the
electromagnetic energy include polarization
characteristics of the electromagnetic energy.

24. A method as set forth in claim 19, wherein said step of providing a data map includes providing the map to indicate spatial phase change.

25. A method as set forth in claim 19, wherein said step of quantifying each segregated portion to provide a spatial phase metric includes associating an information value with each segregated portion.

26. A method as set forth in claim 19, wherein said method is for communication and said step of quantifying each segregated portion to provide a spatial phase metric includes determining a information value from each segregated portion.

27. A method as set forth in claim 19, including processing all spatial phase metrics to derive information.

28. A method of creating an image, said method comprising:

receiving electromagnetic energy proceeding from an object; and

creating an image of the object utilizing only spatial phase characteristics of the electromagnetic energy proceeding from the object.

Abstract

An apparatus (e.g., 10) extracts information from electromagnetic energy via multi-characteristic spatial geometry processing. A portion (e.g., 6) of the apparatus (10) receives electromagnetic energy from a source (e.g., an object 2). The received electromagnetic energy has a plurality of spatial phase characteristics. A portion (e.g., 8A-8X) separates the plurality of spatial phase characteristics of the received electromagnetic energy. A portion (e.g., 14A-14X) identifies spatially segregated portions of each spatial phase characteristic, with each spatially segregated portion of each spatial phase characteristic corresponding to a spatially segregated portion of each of the other spatial phase characteristics in a group. A portion (e.g., 24) quantifies each segregated portion to provide a spatial phase metric of each segregated portion for providing a data map of the spatial phase metric of each separated spatial phase characteristic.

Fig.1

Fig.2

Fig.3A

Fig.3B
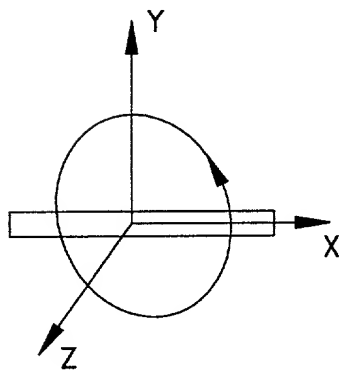
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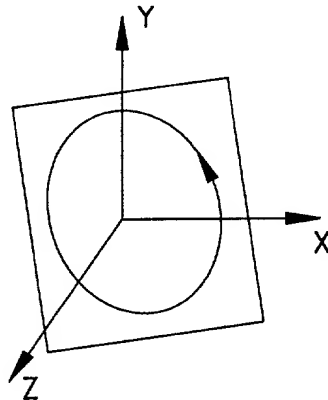
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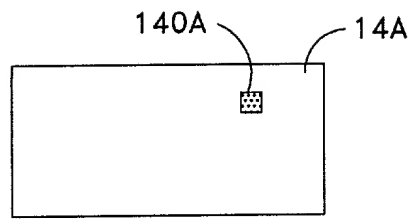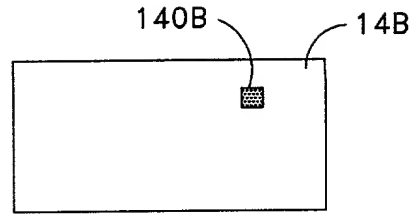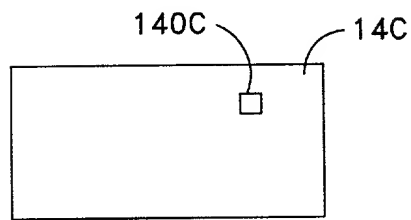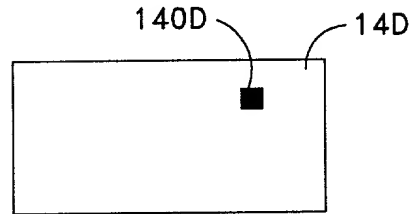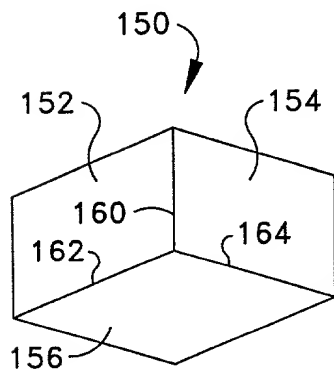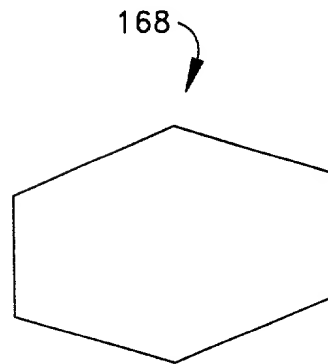
140A — 14A

LINEAR 0°

Fig.4A

140B — 14B

LINEAR 45°

Fig.4B

140C — 14C

LINEAR 90°

Fig.4C

140D — 14D

CIRCULAR LH/RH

Fig.4D

150

152 — 154
160 — 164
162
156

Fig.5

168

Fig.6

170

172 — 174
180
182 — 184
176

Fig.7

IMAGE

Fig.8

TEMPERATURE DIFFERENCE FROM A REFERENCE POINT

Fig.9

RANGE FROM IMAGING SYSYTEM

Fig.10

DENSE SCATTERING
MEDIA

OBJECT

196

192

198

10

SYSTEM

190

194

Fig.11

264

274

284

260

262

266

276

286

268

278

288

270

280

290

272

Xth

282

292

294

296

Fig.12

200

236B

240

242B

14A–14D

232

230

218

14B

202

206

208

210

212

214

204

216

222

224

236A

242A

14A
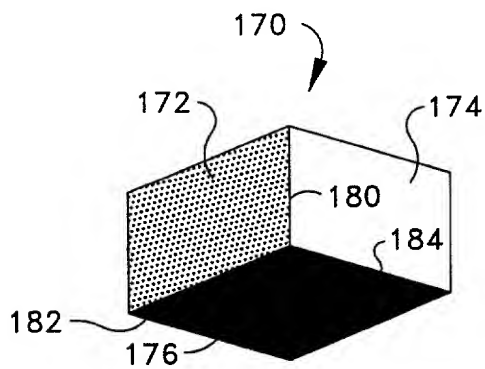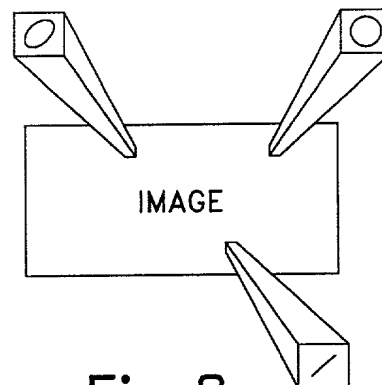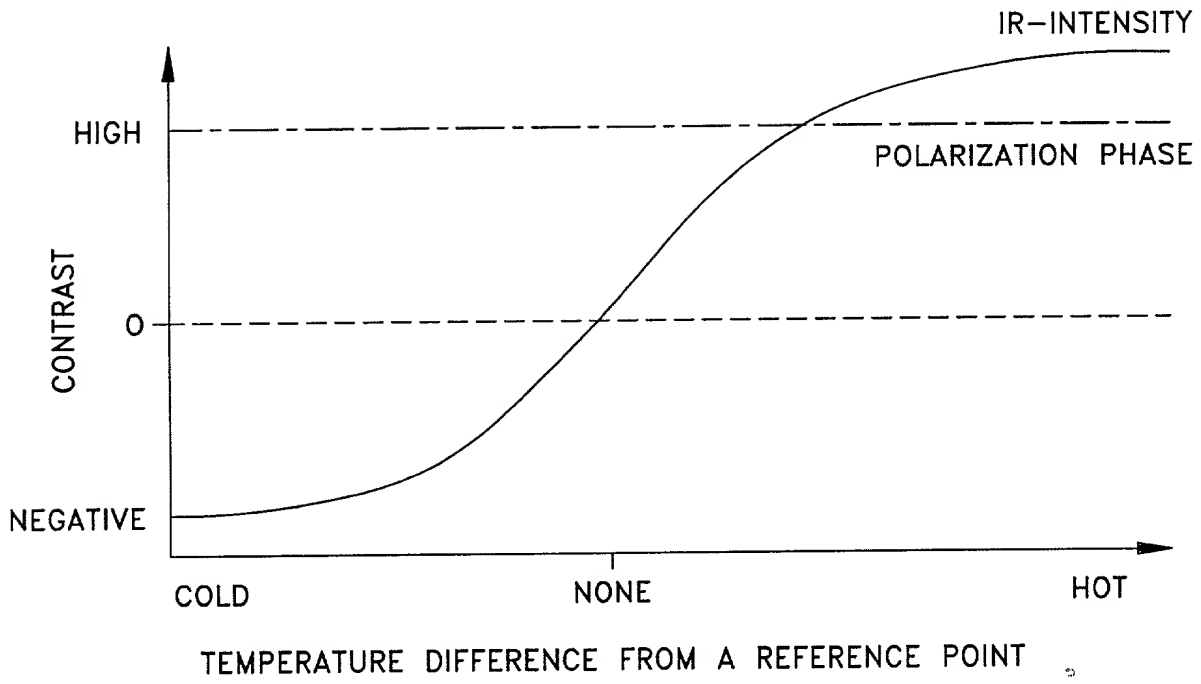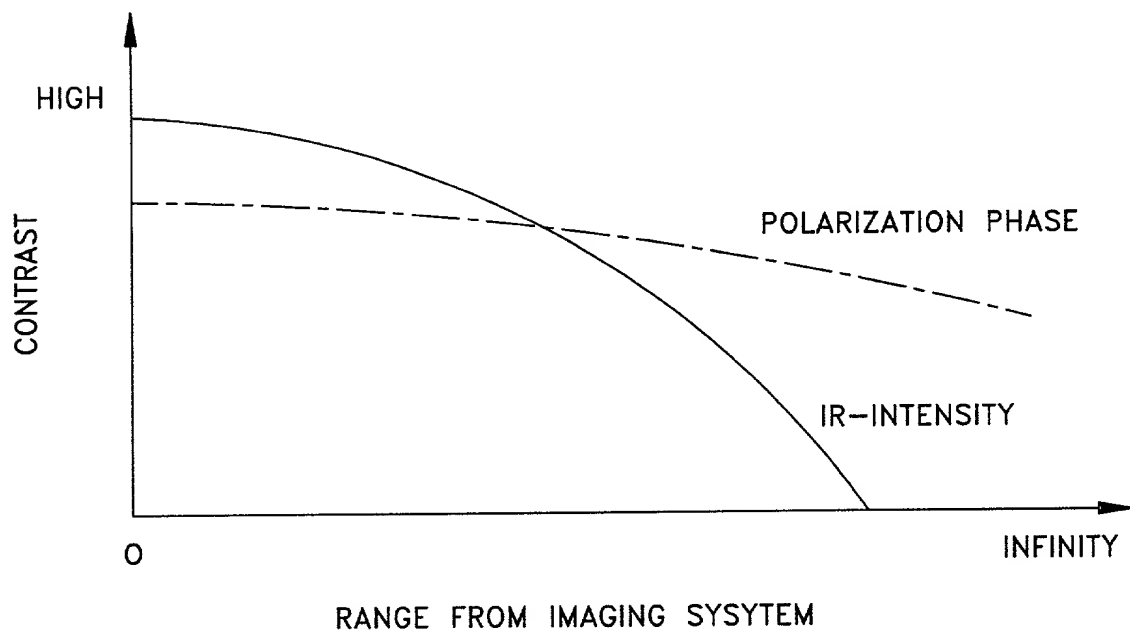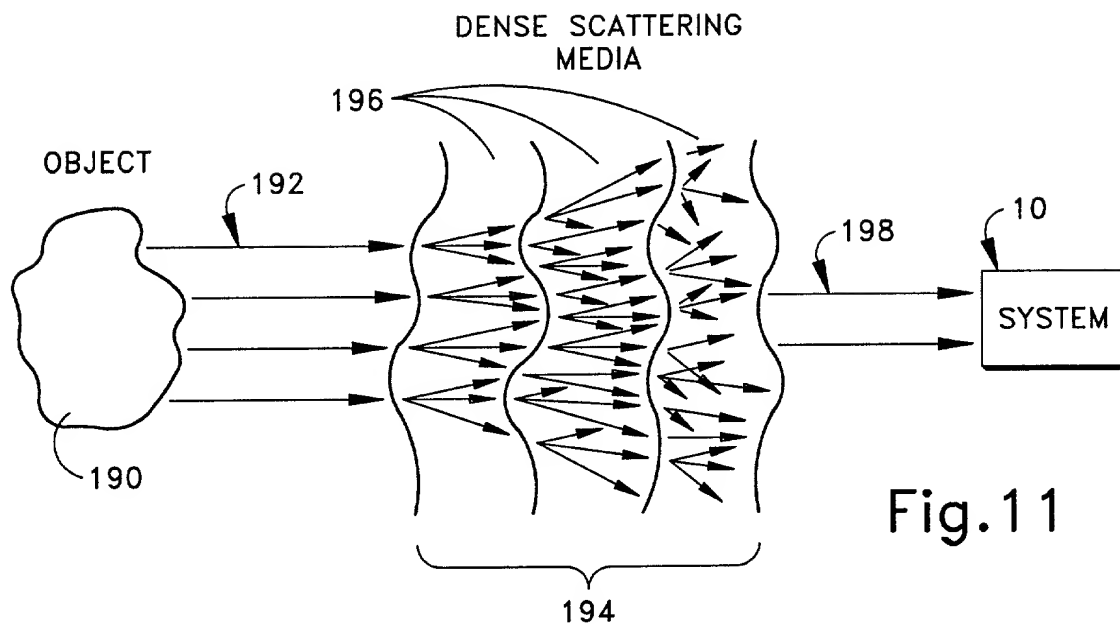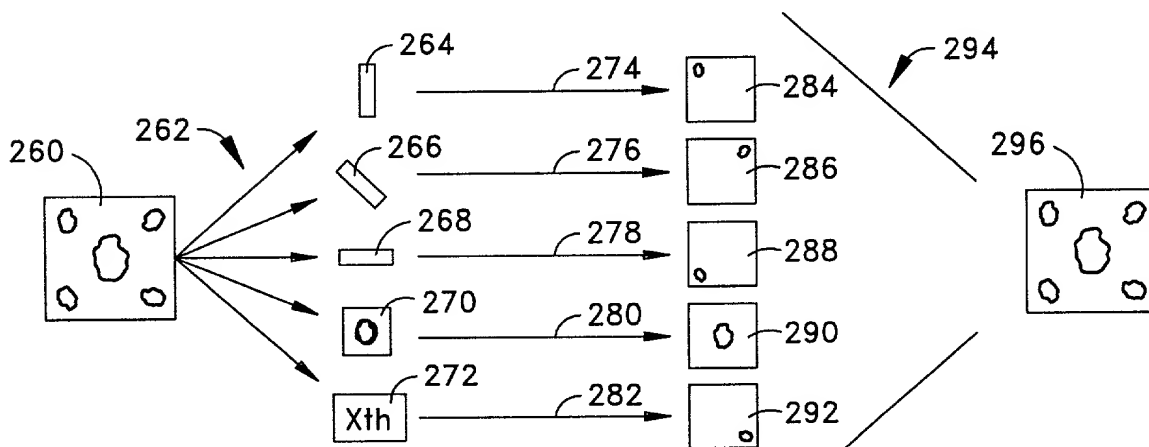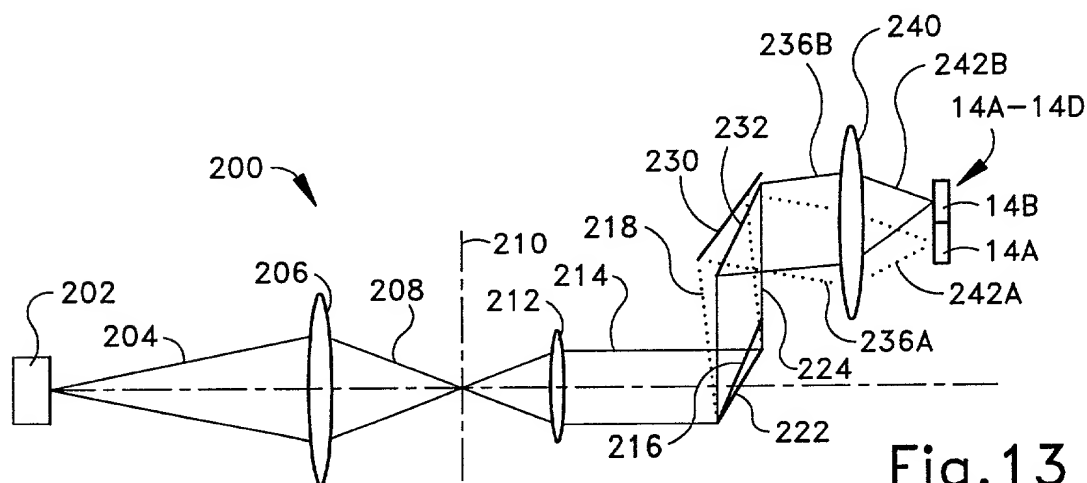
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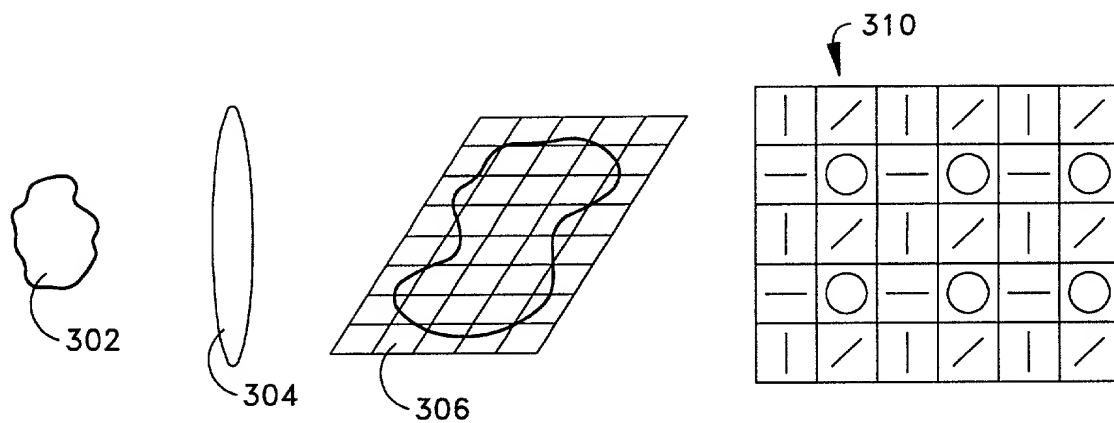
Fig.14
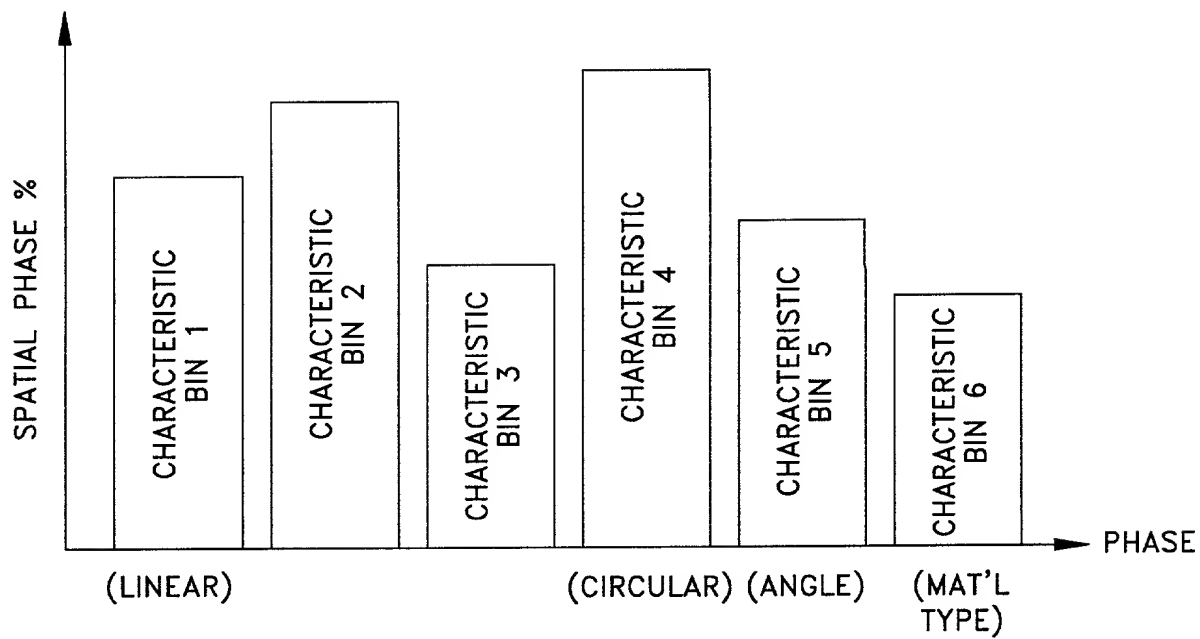
Fig.15

As a below inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled **APPARATUS AND METHOD OF INFORMATION EXTRACTION FROM ELECTROMAGNETIC ENERGY BASED UPON MULTI-CHARACTERISTIC SPATIAL GEOMETRY PROCESSING**, the specification of which:

(check one) ☒ is attached hereto.

☐ was filed on _____ as Application Serial No. _____

and was amended on _____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a).

I hereby claim priority benefits under Title 35, United States Code, §119 of any provisional application(s) listed below and have also identified below any provisional application(s) having a filing date before that of the application on which priority is claimed:

Prior Provisional Application(s):

Priority Claimed

60/145,017	22 July, 1999	☒ Yes ☐ No
(Number)	(Day/Month/Year Filed)	
60/145,194	23 July, 1999	☒ Yes ☐ No
(Number)	(Day/Month/Year Filed)	
60/145,264	26 July 1999	☒ Yes ☐ No
(Number)	(Day/Month/Year Filed)	

I hereby claim the benefit under United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

(Application Serial No.)	(Filing Date)	(Status-patented, pending, abandoned)
(Application Serial No.)	(Filing Date)	(Status-patented, pending, abandoned)

Power of Attorney: As a named inventor, I hereby appoint the following attorneys: Thomas L. Tarolli, Reg. No. 20,177; Robert B. Sundheim, Reg. No. 20,127; Calvin G. Covell, Reg. No. 24,042; Barry L. Tummino, Reg. No. 29,709; Paul E. Szabo, Reg. No. 30,429; James L. Tarolli, Reg. No. 36,029; Ronald M. Kachmarik, Reg. No. 34,512; and Richard S. Wesorick, Reg. No. 40,871, each with full powers of substitution and revocation to prosecute this application and transact all business in the United States Patent and Trademark Office connected therewith.

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Inventor's signature _____ Date _____
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2) Full name of second inventor _____

Inventor's signature _____ Date _____
Residence _____ Citizenship _____
Post Office Address _____ County _____